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AN INTEGRATED LIFE CYCLE INVENTORY FOR DEMOLITION PROCESSES IN THE CONTEXT OF LIFE CYCLE SUSTAINABILITY ASSESSMENT

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Abstract

According to the Life Cycle Assessment in Building and Construction: State-of-the-Art Report (2003), the dismantling and demolition stage of the building life cycle is only sometimes included in the Life Cycle Inventory (LCI) when doing Life Cycle Assessments (LCA). The reason that it is less inventoried in a traditional LCA maybe because this stage is expected to have a negligible environmental impact comparing to other stages in the life cycle of the buildings. When doing a life cycle sustainability assessment considering not only environmental but also economic and social impacts, the impacts of the labor-intensive dismantling and demolition stage may not be possible to disregard anymore, due to the related process costs, health and safety of workers and the influence on the quality of the demolition materials, determining their suitability for high grade recycling. Currently, LCIs of dismantling and demolition processes are rare and reflect only the impacts to the environment and do not include data on economic and social impacts. The present study gives case specific environmental, economic and social LCI data for two demolition processes.

Keywords

Life cycle inventory, life cycle sustainability assessment, demolition methods, costs and social indicators.

1. INTRODUCTION

According to the Life Cycle Assessment in Building and Construction: State-of-the-Art Report (2003) [1], the dismantling and demolition stage of the building life cycle is only sometimes included in the life cycle inventory when doing life cycle assessments. This means, that not all of the processes at the end-of-life of a building are included in the traditional life cycle assessments, which take into account only the environmental impact of a process. The reason that they are not included may be because the dismantling and demolition stage is expected to have much smaller environmental impact than the other stages of the life cycle of the buildings.

When doing a life cycle sustainability assessment including environmental, economic and social impacts, the dismantling and demolition stage may have to be taken into account because

of the related process costs, health and safety of workers and in the present case study the quality of the materials produced (aggregates) and their suitability for reuse instead of virgin raw materials.

LCIs of dismantling and demolition processes are rare. The Building Material Disposal processes in the Ecoinvent database are based mostly on national data for Switzerland, with the exception of the data for the PM emissions, which originates from a study in the UK [2]. The data in the Ecoinvent database reflect only the impacts to the environment and do not include data for economic and social impacts.

Within the EC-FP7 project *Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste (C2CA)*, case-specific environmental, economic and social data are collected for the demolition of EoL buildings. These data are more representative for the Dutch conditions and the demolition methods can be viewed as best practices in the Netherlands. This project aims to develop three innovative technologies for high grade End-of-Life (EoL) concrete recycling, where the purpose of dismantling and demolition is at the first place to generate a clean stream of EoL concrete.

2. METHODOLOGY

The methodology used in this paper to assess the two demolition processes is the life cycle sustainability assessment (LCSA), first proposed by Kloepffer (2003) [3]. Kloepffer argues that there are two options for performing LCSA (2008) [3]. The first option is making three different assessments of a product's system based on the same system boundary and is generally expressed by the formula $LCSA = LCA + LCC + SLCA$, where LCA (also ELCA in this paper) is life cycle assessment, where LCC (also ELCC in this paper) is life cycle costing and SLCA is social life cycle assessment (Kloepffer, 2008) [3]. Heijungs et al. (2010) also see LCA, LCC and SLCA as three different ways of extracting indicators from exactly the same system [4]. The second option, proposed by Kloepffer, is making LCSA by extending the traditional LCA to include LCC and SLCA. According to Kloepffer, making LCSA as an extended LCA "would mean that one LCI is to be followed by up to three impact assessments, possibly leading to the same areas of protection" (2008) [3]. Thus, one of the outlined differences between the two options of doing LCSA is whether or not an integrated life cycle inventory is used by the three assessments. Thus, it becomes necessary to make integrated LCIs.

The present case study shows how the environmental, economic and social aspects of a system can be inventoried in practice for understanding the sustainability of the system. The goal of the study is to analyze the process and the challenges in making a integrated life cycle inventory for a LCSA study of two demolition processes performed on one and the same building and to find suitable ELCC and SLCA inventory indicators, which can be calculated for the functional unit and system boundaries as the ELCA inventory results.

The functional unit of the study is selected to be 1 m² gross floor area (GFA) of a high-rise EoL building. The technological scope of the study are the two demolition technologies, applied for the demolition of the building. The time scope is the project period of demolition: the second half of the year 2011. The system boundaries for the assessment are outlined by the dashed lines in Fig. 1, which also present a general overview of the upstream and downstream processes. Fig. 2 presents the material flow analysis for the demolition processes.

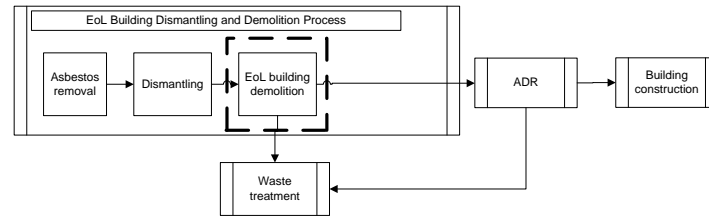


Fig.1. System boundaries for the LCI and upstream and downstream processes.

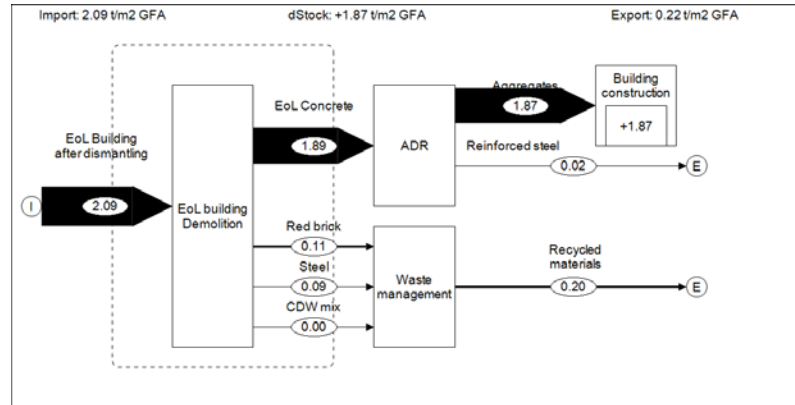


Fig. 2. Material flow diagram for the demolition methods

3. CASE STUDY: TWO METHODS FOR EOL BUILDING DEMOLITION

The EoL building analysed in this paper is a high-rise building located on de Kempkensberg in Groningen in the Netherlands. It has a GFA of 6525 m² and consists of 17 levels, including a basement, ground level, 14 floors and a roof (Fig. 3).

The EoL building demolition project includes three steps: asbestos removal, dismantling and demolition. The paper focuses only on the demolition processes, since the preceding processes (asbestos removal and EoL building dismantling) will be the same for both demolition methods and are assumed to be done properly so that the quality of the EoL concrete produced by the two demolition methods is the same.

Three different demolition methods were used to demolish the building: top-down method to demolish the top 7 floors, high-reach method to demolish the middle 5 floors and short-reach method to demolish the first 2 floors of the tower of the building (Fig. 3). Since the high-reach and the top-down method can replace each other, while the short-reach method cannot substitute any of the other two, the assessments focus on the top 12 floors of the EoL building being demolished completely by one of the methods for high-rise building demolition.

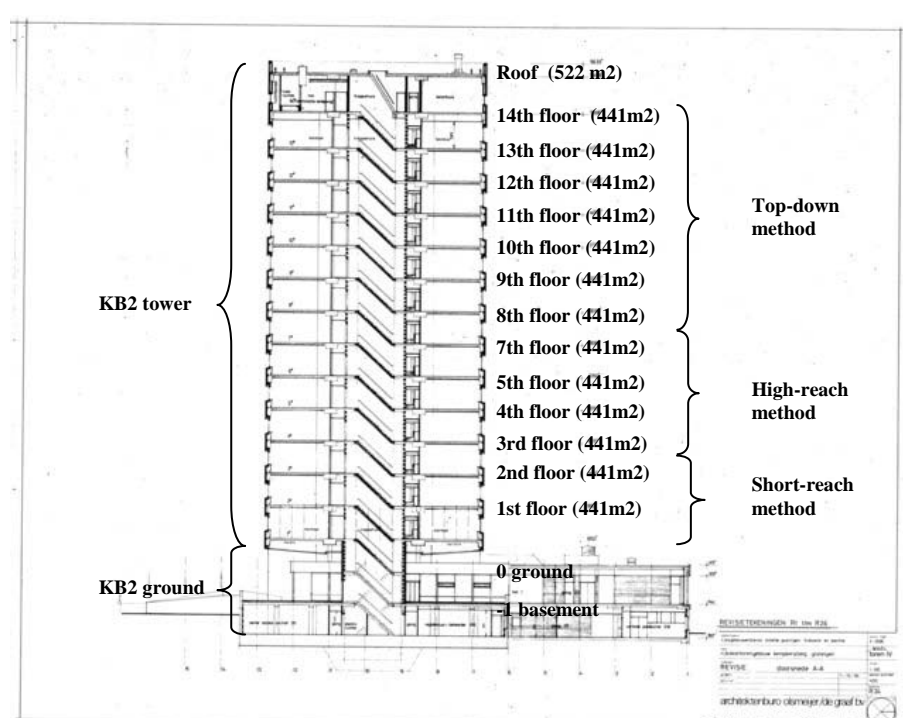


Fig. 3. Section plan of EoL building tower and EoL building ground floors.

Out of the two demolition methods compared, the high-reach method is the one commonly practiced in the Netherlands. The top-down method is an innovative method for the Netherlands. Both methods can generate recyclable streams of materials. The only difference is that with or without good dismantling, the top-down method tends to generate clean waste material streams, while the high-reach method depends on a good dismantling in order to generate the same quality of clean material streams. Once the building has been properly dismantled, the top-down method continues with demolition from the roof and the process of demolishing an EoL building functions like a mirror process to the one of building construction, where instead of putting together building elements one after another, these building elements are consecutively taken out of the EoL building.

4. LIFE CYCLE INVENTORY

4.1. Integrated LCI template

A integrated LCI inventory template was created especially for the project with the goal to try to include the main inventory inputs for the three assessments. The integrated inventory (Table 1 and 2) is based on the concept of input-output tables, thus the items in the rows represent the input materials to the items in the columns. A difference between the integrated LCI table and the input output tables is that the numbers have different units, therefore only the numbers with a common unit can be summed up. The total numbers are represented in bold face. An example of how the table can be read is the following: the high-reach method uses 2 machines for the demolition of the EoL building and these machines cost 16,4 EUR/m² GFA. They consume 5 1/1 m² GFA of diesel for their work, which costs 5,9 EUR/1 m² GFA. The building demolitions takes 0,1 hours/m² GFA and costs 3 EUR/1 m² GFA.

Table 1. Integrated Environmental, Economic and Social LCI for the High-reach Demolition

Inputs/Outputs	ELCA					Waste treatment	ELCC		SLCA			
	EoL building materials	steel [t]	red brick [t]	concrete [t]	CDW mix [t]		Sale of recyclable materials [EUR]	Employment	Local community - Access to material	secondary resources for high-maintenance	secondary resources for low-maintenance	
ELCA	EoL building materials from demolition	0	0	0	0 1/2	2,09	0	0,1	0	0	0	0
	steel [t]	0	0	0	0	0,09	-17,23	0	0	0	0	0
	red brick [t]	0	0	0	0	0,11	0	0	0	0	0	0
	concrete [t]	0	0	0	0	1,89	-4,73	0	0	0	0	0
	CDW mix [t]	0	0	0	0	0,00	0	0	0	0	0	0
	Capital equipment	1,9958	0	0	2	0	0,00	0	0	0	0	0
	transportation vehicle [number]	0	0	0	0	0,00	0	0	0	0	0	0
	demolition vehicle [number]	2	0,08	0,11	1,81	0	0,00	0	0	0	0	0
	Energy consumption	5	0	0	0	0	0,00	0	0	0	0	0
	diesel [l]	5	0	0	0	0	0,00	0	0	0	0	0
ELCC	Waste treatment	0	0	0	0	0	0,00	0	2,09	1,89	0,20	
	Capital cost [EUR]	16	0	0	0	0	0	0	0	0	0	0
	demolition vehicles [EUR]	16,4	0	0	0	0	0	0	0	0	0	0
	Labour cost [EUR]	3	0	0	0	0	0	0	0	0	0	0
	machinist [EUR]	2,8	0	0	0	0	0	0	0	0	0	0
	dismantler, cleaner [EUR]	0	0	0	0	0	0	0	0	0	0	0
	Energy cost [EUR]	6	0	0	0	0	0	0	0	0	0	0
	fuel for demolition vehicles [EUR]	5,9	0	0	0	0	0	0	0	0	0	0
	Waste treatment cost [EUR]	0	0	0	0	0	0,4	0	0	0	0	0
	waste disposal cost [EUR]	0,0	0	0	0	0	0,40	0	0	0	0	0
	Other costs [EUR]	1	0	0	0	0	0	0	0	0	0	0
	company car	1,2	0	0	0	0	0,00	0	0	0	0	0
	Overhead [EUR]	3,2	0	0	0	0	0	0	0	0	0	0
	Sale of recyclable materials [EUR]	0,0	0,0	0,0	0,0	0,0	-21,96	0,00	0	0	0	0
SLCA	Workers - Hours of work	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0	0	0	0
	machinist - hours [number]	0,10	0	0	0	0	0	0	0	0	0	0
	dismantler, cleaner - hours [number]	0	0	0	0	0	0	0	0	0	0	0

Table 2. Integrated Environmental, Economic and Social LCI for the Top-down Demolition

Inputs/Outputs	ELCA					Waste treatment	ELCC		SLCA			
	EoL building materials	steel [t]	red brick [t]	concrete [t]	CDW mix [t]		Sale of recyclable materials [EUR]	Employment	Local community - Access to material	secondary resources for high-maintenance	secondary resources for low-maintenance	
ELCA	EoL building materials from demolition	0	0	0	0 1/2	2,09	0	0,43	0	0	0	0
	steel [t]	0	0	0	0	0,09	-17,23	0	0	0	0	0
	red brick [t]	0	0	0	0	0,11	0	0	0	0	0	0
	concrete [t]	0	0	0	0	1,89	-4,73	0	0	0	0	0
	CDW mix [t]	0	0	0	0	0,00	0	0	0	0	0	0
	Capital equipment	3	0	0	3	0	0,00	0	0	0	0	0
	transportation vehicle [number]	0	0	0	0	0,00	0	0	0	0	0	0
	demolition vehicle [number]	3	0,12	0,16	2,71	0	0,00	0	0	0	0	0
	Energy consumption	5	0	0	0	0	0,00	0	0	0	0	0
	diesel [l]	5	0	0	0	0	0,00	0	0	0	0	0
ELCC	Waste treatment	0	0	0	0	0	0,00	0	2,09	1,89	0,20	
	Capital cost [EUR]	19	0	0	0	0	0	0	0	0	0	0
	demolition vehicles [EUR]	18,6	0	0	0	0	0	0	0	0	0	0
	Labour cost [EUR]	10,80	0	0	0	0	0	0	0	0	0	0
	machinist [EUR]	7,00	0	0	0	0	0	0	0	0	0	0
	dismantler, cleaner [EUR]	3,80	0	0	0	0	0	0	0	0	0	0
	Energy cost [EUR]	5	0	0	0	0	0	0	0	0	0	0
	fuel for demolition vehicles [EUR]	5,2	0	0	0	0	0	0	0	0	0	0
	Waste treatment cost [EUR]	0	0	0	0	0	0,4	0	0	0	0	0
	waste disposal cost [EUR]	0,0	0	0	0	0	0,40	0	0	0	0	0
	Other costs [EUR]	1	0	0	0	0	0	0	0	0	0	0
	company car	0,9	0	0	0	0	0,00	0	0	0	0	0
	Overhead [EUR]	4,3	0	0	0	0	0	0	0	0	0	0
	Sale of recyclable materials [EUR]	0,0	0,0	0,0	0,0	0,0	-21,96	0,00	0	0	0	0
SLCA	Workers - Hours of work	0,43	0,00	0,00	0,00	0,00	0,00	0,00	0	0	0	0
	machinist - hours [number]	0,26	0	0	0	0	0	0	0	0	0	0
	dismantler, cleaner - hours [number]	0,17	0	0	0	0	0	0	0	0	0	0

4.1. Environmental inventory

The environmental inventory for both demolition processes is calculated for the functional unit of 1 m² of GFA and the results for both demolition methods are presented in Table 1 and 2. The inventory includes material and energy consumption and the use of technical equipment. The background processes are excluded from the inventory, because of the lack of information for the ELCC and SLCA for these inventory items. What can be observed from the inventory is that both methods demolish the same amount of materials, while using different number and type of equipment, but consuming almost the same amount of fuel. The top-down method uses 1 bobcat machine, 1 wire crane and 1 20 t excavator, while the high-reach method uses a 30 t excavator and a 65 t excavator to achieve the same task. Although, the top-down method uses more equipment than the high-reach method in terms of numbers, the fuel consumption of the demolition equipment in the top-down method (4,12 l/m² GFA) is less but not by much in comparison to the high-reach method (4,63 l/m² GFA). Thus, just on the basis of the environmental inventory of the foreground processes, it is not possible to conclude, which demolition method is better than the other. The inventory is the second stage of the ELCA and cannot by itself provide a decisive conclusion.

4.2. Cost inventory

The ELCC for this study is to see how demolition options may contribute to sustainable development, relating the economic costs and benefits to the environmental costs and benefits. The correspondence to the ELCA part of the study has been maintained as close as possible. The cost categories for the ELCC were selected with the reference to the UNEP-SETAC *Environmental Life Cycle Costing: A Code of Practice*. The calculation is based on the cost estimation of the demolition company on labour price, fuel price, equipment rental price, waste disposal price, 12% of overhead and sale of recycled materials for the two demolition processes simulated. The cost inventory for both demolition processes is calculated for the functional unit of 1 m² of GFA of an EoL building demolished and the results are presented in Table 1 and 2.

The inventory shows that the largest category of cost for both methods is the capital cost. The second largest cost for Top-down method is labour, which is 3 times bigger than that of High-reach method. The energy cost is comparable. The waste disposal cost and sale for recycled materials are the same, since it was assumed that both methods generate the same quantity and quality of demolition materials.

4.3. Social indicator inventory

The indicator categories for the SLCA were selected at a project workshop from the ones recommended by the UNEP-SETAC *Guidelines for SLCA of Products*. A questionnaire was made and filled out by the demolishing company and the company overseeing the demolition process. Due to confidentiality of a major part of the inventory data, it is not possible to fully disclose the inventory results for the SLCA. Nevertheless, the SLCA inventory results do not change the conclusions of the study, since the indicator values are the same for both demolition methods, since the companies performing the foreground processes are the same. It can be concluded, that company-specific data might not be useful for decision-making in SLCA, when both processes/products are performed/produced by the same company.

There are two indicators, which are process-specific and are possible to be calculated for the functional unit of the study. These indicators are the hours of work created and the amount of secondary resources made available by the process to substitute virgin resources for high- or low-grade uses.

These indicators can be used for decision-making, since their values may vary between processes performed by the same company. Thus, on the basis of the employment created by both demolition methods, it can be concluded that the top-down method is better in terms of social performance, since it creates more working hours (0,43 hours/m² GFA) than the high-reach method (0,10 hours/m² GFA). Furthermore, a distinction can be made between the different employment positions (mechanist and dismantler/cleaner) created by both processes on the basis of the qualifications required for them. Since both demolition methods release the same amount and quality of materials, which can be recycled and re-used, in this study the indicator for access to material resources indicator category is not useful for concluding, which of the two demolition methods is better.

5. DISCUSSION

In the process of conducting the study several methodological challenges were encountered. The first challenge relates to the data collection for a integrated ELCA, ELCC and SLCA inventory. The data collections for all three studies started in parallel, but in the course of data collection and processing it was found that it is better to make the environmental inventory first, followed by the ELCC and the SLCA. The second challenge was calculating the SLCA inventory for the functional unit of the study. The third challenge was to identify the connection points between the inventories, i.e. to identify the inventory items for which there are data available at least for two of the assessments. The following inventory items served as connection points for the LCSA inventory:

- The materials outputs from the demolition processes and the technical demolition equipment used were the connecting inventory items between the ELCA and the ELCC inventories. The cost structure is arranged in a way that the material cost can be coupled to the amount of equipment, energy and demolished materials, using coefficients of unit prices;
- The hours of work necessary for the implementation of both demolition processes served as connection points between the ELCC and the SLCA. Here we can observe a trade-off between the assessments: the longer working hours, which make a demolition method more costly and reflect lower unit productivity, are considered as a positive factor in the SLCA, since more employment hours are created.
- The amount of secondary resources, replacing virgin resources for high- or low-grade use, serves as a connecting point between the social and environmental inventory. Here, no trade-off is observed between the environmental and social results, since the higher the amount of the recycled EoL materials, the greater the access to recycled material resources replacing virgin resources.

The fourth challenge is related to the lack of easily available data for the costs and social indicators for the background processes, thus limiting the integrated LCI to the foreground demolition processes. It is possible to extend a integrated LCI to include environmental data for the background processes, but it is more difficult to do so for the ELCC and the SLCA. Both assessments require data, which is considered confidential by companies and which is very site-specific rather than generic, therefore, making it more difficult to create databases containing generic ELCC and SLCA data.

The fifth challenge is related to the importance of the different ELCC and SLCA indicators for making a definite conclusion for the results of the assessment, as well as the importance (translated to weights) of the aggregated results of each of assessment in a LCSA.

6. CONCLUSIONS AND RECOMMENDATIONS

LCSA is a new approach for sustainability assessment in a life cycle perspective. Traditionally life cycle assessments are data intensive and an integrated life cycle assessment is expected to be even more data intensive. Therefore, it is necessary to come up with tools for managing an integrated LCI and to find more connecting points between the three assessments. The integrated LCI template presented in the paper is applied only to one type of process and is not data intensive, but it might be interesting to be applied to more complex and data intensive processes in order to better assess its strengths and weaknesses.

The integrated LCI for this process can be considered a good tool mostly for the ELCC, for which a preliminary assessment as to which demolition method is better can be reached from inventory indicators. For the SLCA, the integrated LCI is not the best way to present the results of the assessment, since most of the results cannot be related to the functional unit of the study and the richness of the SLCA is lost. The environmental LCI usually takes into account more inventory data than the one presented in the paper, but if a full environmental LCI was presented, it would not be possible to extend the ELCC and SLCA to cover all the background processes, which are included in the ELCA. Thus, this integrated LCI inventory template can be considered a good start, but it has to be acknowledged that it needs to be developed further.

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REFERENCE:

- [1] Kotaji, S., Schuurmans, A. and Edwards, S., "Life-Cycle Assessment in Building and Construction: A State-of-the-Art Report", 2003 (SETAC, 2003).
- [2] Doka, G., "Life Cycle Inventories of Waste Treatment Services: Ecoinvent report No. 13", 2007 (Swiss Centre for Life Cycle Inventories, Dübendorf, 2007).
- [3] Kloeppfer, W., "Life Cycle Sustainability Assessment of Products", *Int J LCA*, **13** (2) (2008) 89 – 95.
- [4] Heijungs R., Huppes, G., and Guinée, J.B., "Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis", *Polymer Degradation and Stability*, **95** (2010) 422-428.
- [5] Swarr, T.E., Hunkeler, D., Klöpffer, W., Pesonen, H., Ciroth, A., Brent, A.C., and Pagan, R., "Environmental Life Cycle Costing: A Code of Practice", (Society of Environmental Toxicology and Chemistry, 2010).
- [6] UNEP, "Guidelines for Social Life Cycle Assessment of Products", (UNEP, 2009).